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A METHOD & DEVICE FOR DETERMINING ATTITUDE USING SPATIAL SHIFT KEY (SSK) SIGNATURES

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FIELD OF THE INVENTION

The present invention relates generally to systems and methods for generating precise attitude determination for a mobile apparatus. In particular, the present invention applies to spatial modulation (SM) systems, which allow precise attitude determination using Spatial Shift Key (SSK) modulated signatures generated from Spatial Shift Key (SSK) antennas.

BACKGROUND TO THE INVENTION

Prior art systems determine attitude by spatially distributing a plurality of position receivers on a mobile platform and concurrently collecting range measurements from a plurality of transmitters at known locations. Range differences are subsequently calculated between position receivers to determine attitude of the user platform (Cohen et al.) These systems are expensive and complicated to install due to the number of position receivers required, and suffer severe attitude degradation in high multipath environments. Therefore, a system that allows robust attitude determination in high multipath environments without the requirement for multiple position receivers is highly desirable.

DISCLOSURE OF THE INVENTION

The present invention discloses a method and device to determine receiver attitude by correlating a Spatial Shift Key (SSK) modulated transmission signature with a Spatial Shift Key (SSK) modulated reception signature. Transmitted Spatial Shift Key (SSK) modulation is achieved by the movement of a radiating means in three dimensional space, such that a predetermined phase, frequency, Integrated Carrier Phase, or Doppler signature is superimposed upon the original transmitted signal. Received Spatial Shift Key (SSK) modulation is achieved by movement of a receive means in three dimensional space, such that a predetermined phase, frequency, Integrated Carrier Phase, or Doppler signature is superimposed upon a received signal. Correlation of a transmitted Spatial Shift Key (SSK) modulation signature with a received Spatial Shift Key (SSK) modulation signature results in spatial synchronization of the radiating means and receive means. With the radiating means attitude known *a priori* the receive means attitude can be determined accurately.

Spatial Shift Key (SSK) modulation can be generated using many different media. For example, sound waves in the audible human spectrum, ultrasonics, infrared, and radio waves can all be used for spatial modulation. In the preferred embodiment of the present invention Radio Frequency (RF) waves are the preferred medium. Therefore, in the preferred embodiment transmitted Spatial Shift Key (SSK) modulation is achieved by the movement of a transmit antenna phase centre in three dimensional space, such that a predetermined phase, frequency, Integrated Carrier Phase, or Doppler signature is superimposed upon the original transmitted signal. Received Spatial Shift Key (SSK) modulation is achieved by movement of a receive antenna phase centre in three dimensional space, such that a predetermined phase, frequency, Integrated Carrier Phase, or Doppler signature is superimposed upon the received signal.

Doppler Signatures

In one embodiment of the present invention a method and device to determine receiver attitude is disclosed by spatially correlating a transmitted Doppler signature with a locally generated receiver Doppler signature. A transmitter is configured to generate a positioning signal which is transmitted through a Spatial Shift Key (SSK) transmit antenna which has predefined motion. This predefined motion repeats at a predetermined interval, thereby inducing a predetermined Doppler signature on the transmitted positioning signal. A receiver is configured to receive the Doppler-modified positioning signal through a Spatial Shift Key (SSK) receive antenna, which is moving with the same predefined motion, and which repeats at the same predetermined interval as the Spatial Shift Key (SSK) transmit antenna. The Spatial Shift Key (SSK) receive antenna therefore induces a second Doppler component on the already Doppler-modified positioning signal. An antenna synchronization control means within the receiver continuously adjusts the Spatial Shift Key (SSK) receive antenna predefined motion to match the transmitted Doppler signature by driving the measured Doppler of the received positioning signal toward zero. Once the received Doppler is nulled (substantially zero) the Spatial Shift Key (SSK) transmit antenna and the Spatial Shift Key (SSK) receive antenna are traveling in unison and are declared spatially synchronized by the receiver. The attitude of the Spatial Shift Key (SSK) receive antenna can now be determined precisely relative to the attitude of the Spatial Shift Key (SSK) transmit antenna by measuring the antenna synchronization control means offset required to bring the antennas into spatial correlation.

A Simple Mechanical Embodiment of the Present Invention

Referring now to Fig. 1, there is depicted a simple mechanical embodiment of the present invention. A positioning signal transmitter 101 is configured with a Spatial Shift Key (SSK) transmit antenna platform 102. The Spatial Shift Key (SSK) transmit antenna platform 102 comprises a transmit antenna 103 mounted at one end of a rotating arm 104, with the other end of the rotating arm 104 connected to a rotating means 105, such as a servo motor. The rotating arm 104 has a fixed length, and revolves at a predetermined rate. In this illustrative embodiment, and for ease of explanation, the transmit antenna 103 rotates at a 1Hz rate (one complete revolution per second), although this rate may be varied to any rate which falls within the

receiver tracking loop bandwidth. The transmitter rotating arm 104 is also configured so that the transmit antenna 103 is at its most northerly point 106 at the beginning of each second. A position receiver 107 is configured with a Spatial Shift Key (SSK) receive antenna platform 108. The Spatial Shift Key (SSK) receiver antenna platform 108 comprises a receive antenna 109 mounted at one end of a rotating arm 110, with the other end of the rotating arm 110 connected to a rotating means 111, such as a servo motor. The rotating arm 110 has identical length to the transmitter rotating arm 104, and is capable of revolving at a variable rate. The position receiver 107 is configured to receive the transmitted positioning signal 112 from the transmit antenna 103 through the receive antenna 109, and measure the Doppler value of the received signal. For ease of explanation assume the clocks of the transmitter 101 and receiver 107 are chronologically synchronous, the Spatial Shift Key (SSK) transmit antenna platform 102 and the Spatial Shift Key (SSK) receive antenna platform 108 are stationary, and the transmit antenna 103 and the receive antenna 109 are rotating. A varying cyclic Doppler will be observed by the position receiver 107 dependent upon the relative motion of the transmit antenna 103 with respect to the receive antenna 109. When the transmit antenna 103 and the receive antenna 109 are rotating in unison both antennas will traverse the most northerly point of their respective rotations concurrently (point 106 and point 113). The antennas are said to be spatially synchronized, and the measured Doppler is at a minimum. When the transmit antenna 103 and the receive antenna 109 are rotating in opposite directions the transmit antenna traverses the most northerly point of its rotation 106 while the receive antenna traverses the most southerly point of its rotation 114. The antennas are said to be spatially unsynchronized, and the measured Doppler is at a maximum. An antenna synchronization control means 115 is configured to adjust the speed of the receive rotating means 111, until the measured received Doppler is at a minimum. The antenna synchronization control means 115 increases or decreases the speed of the rotating receive antenna 109, so that the receive antenna slews into alignment with the transmit antenna rotation. Once the measured Doppler is at a minimum the receive antenna rotation speed is stabilized to the transmit antenna rotation speed (in this example 1Hz) and the transmit antenna and the receive antenna are declared spatially synchronized. When the Spatial Shift Key (SSK) receive antenna platform 108 is reoriented due to user movement the antenna synchronization control means 115 continuously applies corrections to the rotational speed of the receive antenna 109 to maintain spatial synchronization with the transmit antenna 103.

Referring now to Fig. 2, there is a Doppler verses time graph of the above mentioned simple mechanical embodiment of the present invention. Doppler is measured in Hertz and time is measured in tenths of a second. The receive antenna is configured to oscillate at a slightly higher frequency than the transmit antenna, such that the receive antenna is slewed in and out of alignment with the transmit antenna. The minimum Doppler points on the graph 201 & 202 are the points of antenna synchronization, whereas the maximum Doppler points on the graph 203, 204, and 205 are the points where the transmit antenna and the receive antenna were rotating in opposite directions. Referring now to Fig. 3 is a Doppler standard deviation graph of Fig. 2. Comparing Fig. 2 and Fig. 3 it can be clearly seen that spatial synchronization of

antennas is achieved at the points of least Doppler standard deviation 301 & 302. Therefore, in one embodiment of the present invention antenna spatial synchronization is achieved by driving the Doppler standard deviation to its minimum value.

Referring again to Fig. 1. The transmit antenna 103 is configured to traverse its most northerly point 106 at the beginning of each second. Consequently, at a rotational rate of one Hertz it can be seen that the transmit antenna 103 will traverse the most easterly point of its rotation on the quarter second, the most southerly point of its rotation on the half second, and the most westerly point of its rotation on the three quarter second. Therefore, when the receive antenna 109 is spatially synchronized with the transmit antenna, the location of the receive antenna 109 at the beginning of each second represents the most northerly point of its rotation, at the quarter second represents the most easterly point of rotation, at the half second represents the most southerly point of rotation, and at the three quarter second represents the most westerly point of rotation. Furthermore, from this information the orientation of the user relative to North can be determined accurately by measuring the time (modulo 1 second) when the receive antenna 103 traverses the most "forward facing point" of the Spatial Shift Key (SSK) receive antenna platform 108. The most "forward facing point" of the antenna platform being the direction the user is facing. In this simple mechanical embodiment of the present invention a micro switch 117 is placed at the most forward facing point 116 of the Spatial Shift Key (SSK) receive platform 108, below where the rotating receive arm traverses. The micro switch 117 is triggered when the rotating receive arm passes overhead, and a modulo 1 second time stamp is recorded by the receiver. For illustrative example, the synchronized receive antenna 109 traverses the most forward facing point 116 of the platform 108, the micro switch 117 is triggered, and a timestamp of 0.8257 seconds is recorded by the receiver. At one Hertz, one degree of arc is traversed in approximately 2.78 milliseconds. Therefore the orientation of the user is 0.8257 seconds divided by 0.00278 seconds, which equates to 297 degrees. In an alternative embodiment, the angle of the receive antenna rotating arm 110 can be measured with respect to the most forward facing point 116 of the receive platform 108 when traversing the most northerly point 113. This embodiment requires an angular measurement means associated with the receiver rotating arm assembly.

Electronic Movement of Transmit & Receive Antennas

Physical motion of antennas is susceptible to mechanical failure. Therefore in the preferred embodiment of the present invention antenna Doppler Signatures are created electronically. Electronic motion of an antenna can be achieved by spatially distributing antenna elements in a predetermined pattern and successively switching antenna elements to emulate antenna movement. Referring now to Fig. 4, there is depicted a simple electronically switched embodiment of the present invention. A positioning signal transmitter 401 is configured with a Spatial Shift Key (SSK) antenna platform 402. The Spatial Shift Key (SSK) transmit antenna platform 402 comprises an array of transmit antennas 403-1 to 403-8 mounted in a circular pattern. Each transmit antenna element is connected to a Radio Frequency (RF) switch 404, which

in turn is connected to the transmitter 401. Each RF switch 404 is also connected to a control means 405, such as a microprocessor, which can individually activate and deactivate each RF switch 404 as required. The control means 405 is configured to activate and deactivate each antenna element 403-1 to 403-8 in succession, such that the transmitted signal traverses a circular motion around the array. This circular motion induces a predetermined cyclic Doppler signature upon the transmitted positioning signal 406.

A position receiver is configured with a Spatial Shift Key (SSK) receive antenna platform 407 comprising an array of receive antennas 408-1 to 408-8 mounted in a circular pattern of identical radius to that of the transmit array 403-1 to 403-8. Each receive antenna element 403 is connected to a Radio Frequency (RF) switch 409, which in turn is connected to the receiver 410. Each RF switch 409 is also connected to an antenna synchronization control means 411, such as a microprocessor, which can individually activate and deactivate each RF switch 409 as required. The antenna synchronization control means 411 is configured to activate and deactivate each receive element 408-1 to 408-8 in succession, such that the received signal traverses a circular motion around the array. This circular motion induces a Doppler signature upon the received positioning signal. The antenna synchronization control means 411 is configured to adjust the time of the receiver antenna RF switching 409, until the measured received Doppler is at a minimum. The antenna synchronization control means 411 increases or decreases the frequency of the antenna switching, such that the receive antenna slews into alignment with the transmit antenna rotation. Once the measured Doppler is at a minimum the receive antenna switching speed is stabilized to the transmit antenna switching speed and the transmit antenna array and the receive antenna array are declared spatially synchronized. When the Spatial Shift Key (SSK) receive antenna platform 408 is reoriented due to user movement the antenna synchronization control means 411 continuously applies adjustments to the frequency of the receive antenna RF switching 409 to maintain spatial synchronization with the transmit antenna.

The transmit antenna array 403-1 to 403-8 is configured to activate its most northerly antenna element 403-1 at the beginning of each second. Consequently, at a rotational rate of one Hertz it can be seen that the most easterly transmit antenna element 403-3 will be activated on the quarter second, the most southerly transmit antenna element 403-5 will be activated on the half second, and the most westerly transmit antenna element 403-7 will be activated on the three quarter second. Therefore, when the receive antenna array 408-1 to 408-8 is spatially synchronized with the transmit antenna array, the location of the currently active receive antenna at the beginning of each second represents the most northerly point of the arrays rotation, at the quarter second represents the most easterly point of rotation, at the half second represents the most southerly point of rotation, and at the three quarter second represents the most westerly point of rotation. Furthermore, from this information the orientation of the spatially modulated receive platform 407 relative to North can be determined accurately by measuring the time (modulo 1 second) when the receive antenna 408-7 positioned at the most forward facing point 412 of the Spatial Shift Key (SSK) receive antenna platform 407 is activated (switched on). The most forward facing point of the antenna platform being the

direction the user is facing. For illustrative example, in a spatially synchronized receiver antenna array the most forward facing antenna element 408-7 positioned at the front of the Spatial Shift Key (SSK) antenna platform 412, is activated and a timestamp of 0.3759 seconds is recorded by the receiver. At one Hertz, one degree of arc is traversed in approximately 2.78 milliseconds. Therefore the orientation of the user is 0.3759 seconds divided by 0.00278 seconds, which equates to 135.2 degrees.

Multipath effects on Doppler Signatures

Multipath causes power fades and destabilization of receiver positioning signal tracking loops. A stationary Spatial Shift Key (SSK) receive antenna may experience cyclic power fades as the receive antenna cuts through the same fade each time it traverses the same location in its spatial pattern. This causes a consistent destabilization of the receiver carrier tracking loop, which appears as a cyclic Doppler variation to the position receiver. The antenna synchronization control means may mistake this Doppler variation as a spatial incoherency in the Spatial Shift Key (SSK) receive antenna, and erroneously attempt to correct the antenna synchronization. Therefore, cyclic Doppler variation due to multipath must be identified and eliminated from the receiver antenna synchronization control means, so that consistent spatial synchronization of the Doppler signatures is maintained. One embodiment of the present invention achieves this by using power measurements to identify multipath fades, and eliminating the Doppler measurements associated with the power fades. The antenna synchronization control means only uses Doppler measurements associated with acceptable power levels, where the carrier tracking loops are functioning acceptably. In the preferred embodiment acceptable tracking levels are determined by measuring the average received power (ARP) over the signature pattern period, and determining a threshold power level below the ARP in which the Doppler measurements are deemed unacceptable. Tracking loop stability can be affected for some time after signal power resumption. Therefore, in the present invention a second threshold is set for resumption of Doppler measurements by the antenna synchronization control means. For illustrative example, the antenna synchronization control means ignores Doppler measurements when the signal power level drops below ARP minus 2dB, and resumes use of the Doppler measurements when signal power levels increase to ARP plus 1dB. In other words, any signal that drops 2dB below ARP is not used by the antenna synchronization control means, and is not used again until it increases to 1dB above ARP.

Referring now to Fig. 5, there is shown an instantaneous power versus time graph 501, and an ARP versus time graph 502 of the previous experiment discussed in Fig. 2 and Fig. 3 above. Varying cyclic power fades are evident in the instantaneous power measurements with each complete revolution of the receive antenna. The ARP measurements 502 are more consistent than the instantaneous measurements, thus allowing a stable power reference. Referring again to Fig. 2 it can be seen that Doppler oscillations are still evident when the antennas are spatially correlated 201 & 202. This is predominantly due to tracking loop multipath destabilization, although physical inconsistencies in antenna diameter are also a contributing factor.

Doppler Induced by User Movement

User movement of the Spatial Shift Key (SSK) receive antenna platform induces an additional Doppler component upon the received Doppler signature. Doppler induced by user movement must be eliminated from the antenna synchronization control means, so as not to corrupt the spatial synchronization of antennas. This can be achieved using one, or a combination, of the following methods:

1. Configure and transmit a unique static positioning signal in close proximity to the Spatial Shift Key (SSK) transmit antenna, such that both the static and Spatial Shift Key (SSK) positioning signals are chronologically synchronous and have substantially the same unit vector with respect to a roving position receiver. Positioning signals received with substantially the same unit vectors exhibit substantially the same user movement Doppler measurements at a roving position receiver. Configure the position receiver with a Spatial Shift Key (SSK) receive antenna and a static receive antenna. Receive Spatial Shift Key (SSK) transmit Doppler signatures through the Spatial Shift Key (SSK) receive antenna, and receive static (non-signature) positioning signals through the static receive antenna. Difference the received static signal and the Spatial Shift Key (SSK) signal to eliminate user movement, and supply the differenced signal to the antenna synchronization control means.

2. Receive both Spatial Shift Key (SSK) and static positioning signals through the Spatial Shift Key (SSK) receive antenna and difference the transmitted static signal and the transmitted Spatial Shift Key (SSK) signal to eliminate the majority of user movement. Supply the differenced signal to the antenna synchronization control means.

3. Configure an Inertial Navigation System (INS) with the user receiver. Difference the INS signal and the Spatial Shift Key (SSK) receive antenna signal to eliminate user movement. Supply the differenced signal to the antenna synchronization control means.

4. Filter low frequency user movement from the relatively high frequency Doppler signature. Supply the high-pass filtered signal to the antenna synchronization control means.

5. Apply Differential Doppler Signatures (as described below).

Differential Doppler Signatures

The present invention also discloses a method and device to determine receiver attitude by spatially correlating a plurality of transmitted Doppler signatures with a plurality of locally generated receiver

Doppler signatures. A transmitter is configured to generate a plurality of positioning signals which are transmitted through a plurality of Spatial Shift Key (SSK) transmit antennas, with each antenna transmitting a unique positioning signal and having a unique predefined motion. Each unique predefined motion repeats at a unique predetermined interval, thereby inducing a unique predetermined Doppler signature on each transmitted positioning signal. A receiver is configured to receive the plurality of unique Doppler-modified positioning signals through a plurality of Spatial Shift Key (SSK) receive antennas, with each receive antenna receiving a single unique positioning signal. Each receive antenna is configured to move with the same unique predefined motion, and repeat at the same unique predetermined interval, as its respective transmit antenna. An antenna synchronization control means within the receiver continuously adjusts the plurality of Spatial Shift Key (SSK) receive antenna predefined motion to match the plurality of unique Spatial Shift Key (SSK) transmit Doppler signatures by driving the differenced Doppler measurement of the received positioning signals to zero. Once the received Doppler difference is nulled (substantially zero) the Spatial Shift Key (SSK) transmit antennas and the Spatial Shift Key (SSK) receive antennas are traveling in unison and are spatially synchronized. The attitude of the Spatial Shift Key (SSK) receive antennas can now be determined precisely relative to the attitude of the Spatial Shift Key (SSK) transmit antennas by measuring the antenna synchronization control means offset required to bring the antennas into spatial correlation. Extraneous Doppler measurements due to user movement are eliminated in the differencing process.

Referring now to Fig. 6, there is depicted a simple differential mechanical embodiment of the present invention. A positioning signal transmitter 601 is configured with a Spatial Shift Key (SSK) transmit antenna platform 602. The Spatial Shift Key (SSK) transmit antenna platform 602 comprises a first transmit antenna 603 mounted at one end of a rotating arm 604 and transmitting a first unique positioning signal 605, a second transmit antenna 606 mounted at the opposite end of the rotating arm 604 and transmitting a second unique positioning signal 607, with the centre of the rotating arm 604 connected to a rotating means 608, such as a servo motor. The rotating arm 604 has a fixed length, and revolves at a predetermined rate. In this illustrative embodiment, and for ease of explanation, the transmit antennas 603 & 606 rotate at a 1Hz rate (one complete revolution per second), although this rate may be varied to any rate which falls within the receiver tracking loop bandwidth. The transmit rotating arm 604 is also configured so that the first transmit antenna 603 is at its most northerly point 609, and the second transmit antenna 606 is at its most southerly point 610, at the beginning of each second. A position receiver 611 is configured with a Spatial Shift Key (SSK) receive antenna platform 612. The Spatial Shift Key (SSK) receive antenna platform 612 comprises a first receive antenna 613 mounted at one end of a rotating arm 614, and receiving the first unique positioning signal 605 transmitted from the first transmit antenna 603, a second receive antenna 615 mounted on the opposite end of the rotating arm 614 and receiving the second unique positioning signal 607 transmitted from the second transmit antenna 606, with the centre of the rotating arm 614 connected to a rotating means 616, such as a servo motor. The rotating arm 616 has

identical length to the transmit rotating arm 604, and is capable of revolving at a variable rate. The position receiver 611 is configured to receive the first transmitted positioning signal 605 from the first transmit antenna 603 through the first receive antenna 613, and measure the Doppler value of the first received positioning signal 605. Concurrently the position receiver 611 is configured to receive the second transmitted positioning signal 607 from the second transmit antenna 606 through the second receive antenna 615, and measure the Doppler value of the second received positioning signal. Assuming the clocks of the transmitter 601 and receiver 611 are chronologically synchronous, a varying cyclic Doppler value will be observed by the position receiver 611 dependent upon the relative motion of the transmit antennas 603 & 606 with respect to the receive antennas 613 & 615. When the first transmit antenna 603 and the first receive antenna 613 are rotating in unison both antennas will traverse the most northerly point of their respective rotations concurrently (point 609 and point 617). Simultaneously, the second transmit antenna 606 and the second receive antenna 615 will traverse the most southerly point of their respective rotations (point 610 and point 618). The antennas are said to be spatially synchronized, with the measured Doppler between the first transmit antenna 603 and first receive antenna 613 being at a minimum, and the measured Doppler between the second transmit antenna 606 and the second receive antenna 615 being at a minimum also. The first received Doppler observation is then subtracted from the second received Doppler observation, which yields a substantially zero Doppler difference. This substantially zero Doppler difference is unperturbed by user movement, as all user induced Doppler is removed in the process of differencing the first positioning signal 605with the second positioning signal 607. When the first transmit antenna 603 and the first receive antenna 613 are rotating in opposite directions the first transmit antenna traverses the most northerly point of its rotation 609 while the first receive antenna traverses the most southerly point of its rotation 618. Simultaneously, the second transmit antenna traverses the most southerly point of its rotation 610, while the second receive antenna traverses the most northerly point of its rotation 617. The antennas are said to be spatially unsynchronized, with the measured Doppler between the first transmit antenna 603 and first receive antenna 613 being at a maximum, and the measured Doppler between the second transmit antenna 606 and the second receive antenna 615 being at a maximum also. Importantly, these Doppler observations are out of phase with one another when measured by the position receiver 611. The first received Doppler observation is then subtracted from the second received Doppler observation, which yields a doubling of the maximum measured Doppler, due to the out-of-phase nature of the two observables. This doubled maximum Doppler difference is unperturbed by user movement, as all user induced Doppler is removed in the process of differencing. Furthermore, the Doppler difference supplies the antenna synchronization control means 619 with a higher resolution control signal, such that improved spatial correlation of Doppler signatures may be achieved. The antenna synchronization control means 619 is configured to adjust the speed of the receive rotating means 616, until the measured received Doppler difference is at a minimum. The antenna synchronization control means 619 increases or decreases the speed of the rotating receive antennas 613 & 615, so that the receive antennas slew into alignment with the transmit antenna rotation. Once the measured Doppler difference is at a minimum the receive antenna

rotation speed is stabilized to the transmit antenna rotation speed (in this example 1Hz) and the transmit antennas and the receive antennas are declared spatially synchronized. When the Spatial Shift Key (SSK) receive antenna platform 612 is reoriented due to user movement the antenna synchronization control means 619 continuously applies corrections to the rotational speed of the receive antenna rotating arm 614 to maintain spatial synchronization with the transmit antenna.

Differential Doppler Signatures may also be applied to electronically switched arrays, as described previously in this document.

Multipath mitigation using Differential Doppler Signatures

Differential Doppler Signatures consist of a plurality of positioning signals that are transmitted from, and received at, different locations concurrently. Therefore, a position receiver configured to receive the transmitted positioning signals will experience different multipath effects on each positioning signal at any given instant in time. The received power of the plurality of signatures are substantially the same in a multipath free environment, as the distances from the transmit antennas to the receive antennas are substantially the same. A robust Average Received Power (ARP) measurement can be determined by averaging the plurality of received positioning signal power levels over the Doppler signature period. Instantaneous Positioning signal power levels that drop below the ARP by a predetermined amount are considered to be adversely affected by multipath and their Doppler measurements are either eliminated from the antenna synchronization control means measurement or alternatively the Doppler measurements are corrected before being applied to the antenna synchronization control means.

When a Spatial Shift Key (SSK) receive antenna platform, configured to receive a plurality of Doppler signatures, is spatially synchronized with a Spatial Shift Key (SSK) transmit antenna platform transmitting a plurality of Doppler signatures, the individual tracking values for each transmit/receive pair are substantially the same. When a first receive antenna enters a multipath fade the associated receiver tracking loop Doppler value will be corrupted according to the severity of the fade. However, a second receive antenna which concurrently is not in a multipath fade will have an associated receiver tracking loop Doppler value which is accurate. This accurate tracking loop Doppler value can be used by the first receiver tracking loop while its own value is corrupt. Once the multipath fade has been traversed by the first receive antenna, and receive power has been restored, tracking loop control is resumed by the first receive channel tracking loop. Therefore, the present invention allows for non-corrupt tracking loop values to be substituted for corrupt tracking loop values, such that greater tracking performance is achieved in multipath environments. In practice, this method provides a system whereby tracking values are traded between tracking loops as each receive antenna enters and exits multipath fades. Furthermore, the mean of the plurality of corrected Doppler values are subsequently available for user movement Doppler measurements, thus providing a more robust positioning method in multipath environments.

All tracking loops within the user receiver measure a user movement Doppler value, a Doppler signature value, and a multipath corruption Doppler value. When the Spatial Shift Key (SSK) antennas are spatially synchronized the measured Doppler signature values are substantially zero, leaving the user movement and the multipath corrupted Doppler values remaining. User movement Doppler values are subsequently eliminated in the differencing process, thus leaving multipath corrupted Doppler remaining.

Transmitters using the same Doppler Signature

The present invention also discloses a method and device to determine receiver attitude by spatially correlating a plurality of identical transmitted Doppler signatures with a single locally generated receiver Doppler signature. A plurality of spatially distributed transmitters are configured to generate unique positioning signals which are transmitted through Spatial Shift Key (SSK) transmit antennas. Each Spatial Shift Key (SSK) transmit antenna is configured with identical attitude (orientation) and identical predefined motion, such that all transmit antennas move in unison. The unique predefined motion repeats at a predetermined interval, thereby inducing an identical predetermined Doppler signature on each transmitted positioning signal. A receiver is configured to receive the Doppler-modified positioning signals through a Spatial Shift Key (SSK) receive antenna, which is moving with the same predefined motion, and which repeats at the same predetermined interval as all transmit antennas. The Spatial Shift Key (SSK) receive antenna therefore induces a second Doppler component on the already Doppler-modified positioning signals. An antenna synchronization control means within the receiver continuously adjusts the Spatial Shift Key (SSK) receive antenna predefined motion to match the Spatial Shift Key (SSK) transmit Doppler signatures by driving the measured Doppler of the received positioning signals toward zero. Once the received Doppler is nulled (substantially zero) the Spatial Shift Key (SSK) transmit antennas and the Spatial Shift Key (SSK) receive antenna are traveling in unison and are spatially synchronized. The attitude of the Spatial Shift Key (SSK) receiver antenna can now be determined precisely relative to the attitude of the Spatial Shift Key (SSK) transmit antennas by measuring the antenna synchronization control means offset required to bring the antennas into spatial correlation.

Attitude Determination using Pattern Recognition of Doppler Signatures

In a further embodiment of the present invention the antenna synchronization control means, as previously described, is replaced with a pattern recognition algorithm to determine attitude. Doppler Signatures are generated and transmitted through Spatial Shift Key (SSK) antennas, and receivers are configured with Spatial Shift Key (SSK) receive antennas as previously described. The Spatial Shift Key (SSK) receive antenna generates its predetermined Doppler Signature with a fixed orientation. That is, the antenna traverses its most forward facing position at the top of each epoch, and doesn't attempt to correlate with the transmitted Doppler Signature. Different orientations of the receive antenna produce different Doppler patterns over the cycle period. These Doppler patterns are matched with predetermined Doppler patterns

associated with particular receive antenna orientations, which have been stored in the receiver memory, such that orientation is determined. Therefore, the present invention discloses the use of pattern recognition of Spatial Shift Key (SSK) antennas to determine platform attitude.

Three Dimensional Doppler Signatures for Three Dimensional Attitude

The present invention also discloses a method and device to produce three dimensional attitude determination using three-dimensional Doppler signatures. Three-dimensional Doppler signatures are produced using Spatial Shift Key (SSK) antennas that are moved in three dimensional space. Three dimensional movement can be achieved by spatially distributing antenna elements in a three dimensional shape, such as a tetrahedron, and successively switching between elements to generate spatial modulation (SM).

Improved Resolution of an Electronically Switched Antenna Array

The present invention also discloses a method and device to produce high resolution spatial modulation without physical movement of antenna elements. A plurality of antenna elements are each connected to separate radio frequency (RF) digital attenuators and spatially distributed within a quarter wavelength of one another. A microprocessor is configured to control the level of attenuation from each digital attenuator, such that the gain of each antenna element can be individually varied. When two adjacent elements are gained equally the effective antenna phase centre is located half way between the two elements. When the first antenna element has no attenuation applied, and the second antenna element has full attenuation applied, the phase centre is substantially positioned at the first antenna position. When gain is inversely applied to antenna elements the effective phase centre will be panned between elements. In the preferred embodiment antenna elements are placed in a three dimensional shape, such as a tetrahedron, so that three-dimensional spatial modulation can be achieved. In a further embodiment of the present invention Spatially Modulated (SM) antenna arrays are configured with dimensions larger than one quarter wavelength by building arrays with adjacent antenna elements being within a quarter wavelength of one another. For example, antenna elements are positioned in a circle, or a sphere, with a quarter wavelength spacing between each adjacent element. High resolution spatial modulation is achieved by panning between pairs of successive adjacent antenna elements.

Chronological Synchronization of SM Signatures

Chronological synchronization of receiver time with transmitter time can be achieved in a number of ways:

1. A receiver computes a single-point position solution from a synchronous network of positioning-unit devices. This will yield time accuracies in the order of nanoseconds.

2. A receiver receives a time stamp modulated on a single transmitted positioning signal. This time stamp will be delayed by the time it takes the radio wave to travel from the transmitter to the receiver, known as the signal propagation delay. Time stamps modulated on a single transmitted positioning signal will therefore yield time accuracies in the order of microseconds.

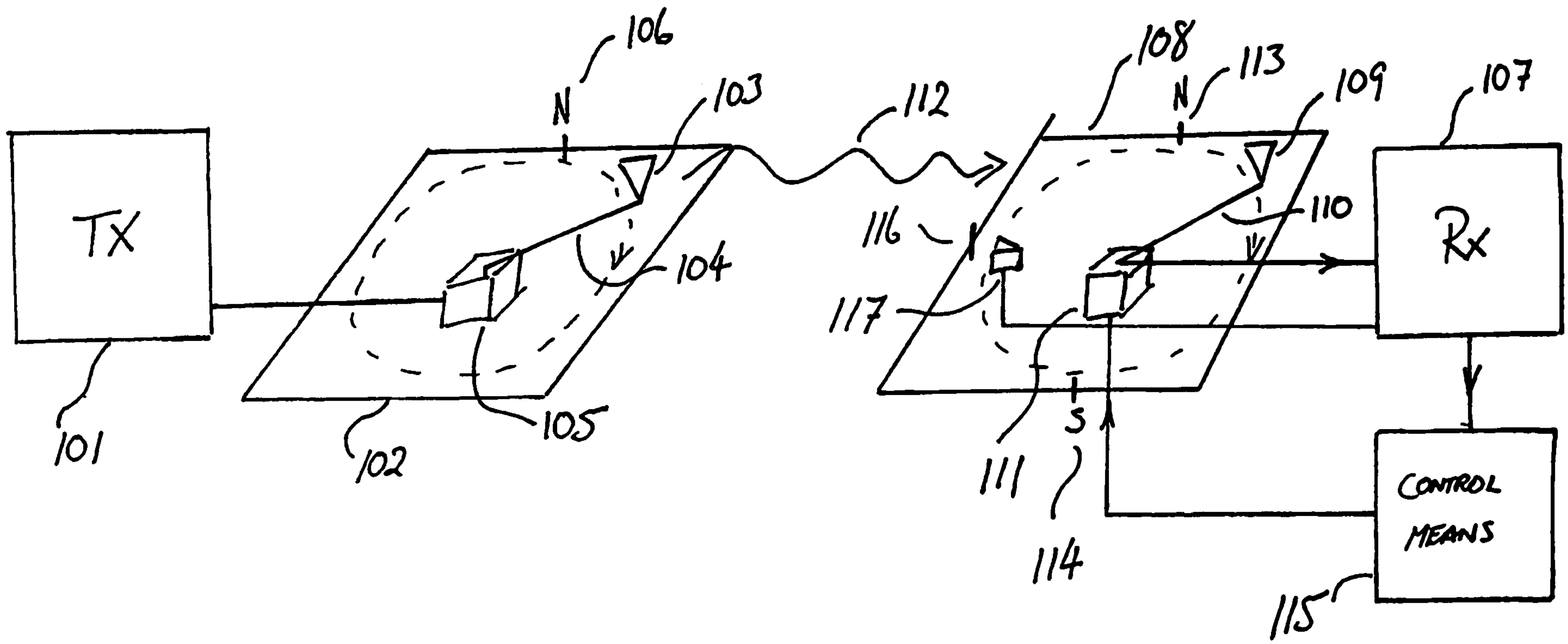
Attitude using One Differential Doppler Signature

A position receiver configured to receive a Differential Doppler Signature can determine attitude using at least one transmitted Differential Doppler signature. The process of differencing the first Doppler signature with the second Doppler signature eliminates both user movement Doppler and also receiver clock drift. Therefore, the differenced signal can be used to determine antenna spatial synchronization without accurate time being available. The time stamp modulated on the Differential Doppler positioning signals is sufficient to determine time to the microsecond level, which will yield an orientation error in the order of several thousandths of a degree. This method can also be applied to a pair of Spatial Shift Key (SSK) and static positioning signals: Configure and transmit a unique static positioning signal in close proximity to the Spatial Shift Key (SSK) transmit antenna, such that both the static and Spatial Shift Key (SSK) positioning signals are synchronous and have substantially the same unit vector with respect to a roving position receiver. Positioning signals received with substantially the same unit vectors exhibit substantially the same user movement Doppler measurements at a roving position receiver. Configure the position receiver with a Spatial Shift Key (SSK) receive antenna and a static receive antenna. Receive Spatial Shift Key (SSK) transmit Doppler signatures through the Spatial Shift Key (SSK) receive antenna, and receive static (non-signature) positioning signals through the static receive antenna. Difference the received static signal and the Spatial Shift Key (SSK) signal to eliminate user movement and receiver clock drift, and supply the differenced signal to the antenna synchronization control means.

Spatially Modulated Phase Signatures

In a further embodiment of the present invention a method and device to determine receiver attitude is disclosed by spatially correlating a transmitted phase signature with a locally generated receiver phase signature. A transmitter is configured to generate a positioning signal which is transmitted through a Spatial Shift Key (SSK) transmit antenna which has predefined motion. This predefined motion repeats at a predetermined interval, thereby inducing a predetermined phase signature on the transmitted positioning signal. The phase signature is modulated at a rate below the receiver integration period, but above the receiver tracking loop bandwidth. A receiver is configured to receive the phase-modified positioning signal through a Spatial Shift Key (SSK) receive antenna, which is moving with the same predefined motion, and which repeats at the same predetermined interval as the Spatial Shift Key (SSK) transmit antenna. The Spatial Shift Key (SSK) receive antenna therefore induces a second phase component on the already phase-modified positioning signal. An antenna synchronization control means within the receiver continuously

adjusts the Spatial Shift Key (SSK) receive antenna predefined motion to match the transmitted phase signature by searching for the greatest phase correlation. That is, all phase measurements will be substantially the same when the antennas are in spatial synchronization. Once the received phase is correlated (substantially the same) the Spatial Shift Key (SSK) transmit antenna and the Spatial Shift Key (SSK) receive antenna are traveling in unison and are spatially synchronized. The attitude of the Spatial Shift Key (SSK) receiver antenna can now be determined precisely relative to the attitude of the Spatial Shift Key (SSK) transmitter antenna by measuring the antenna synchronization control means offset required to bring the antennas into spatial correlation



TX
101
102
N
106
103
104
105
112
108
N
113
109
110
116
117
111
S
114
Rx
107
CONTROL
MEANS
115

FIG. 1

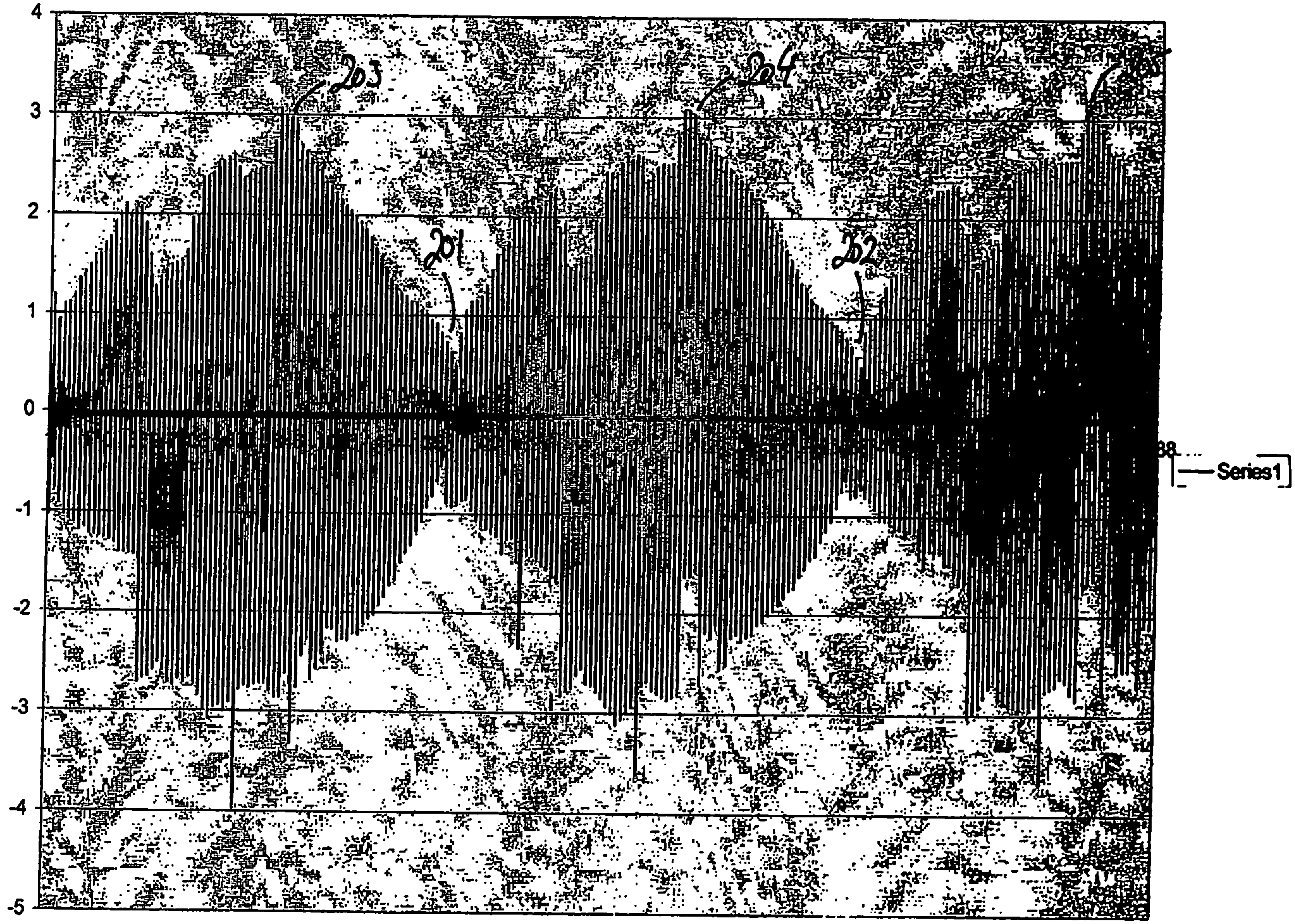


FIG 2


2.5
2
1.5
1
0.5
0
1 172 343 514 685 856 1027 1198 1369 1540 1711 1882 2053 2224 2395 2566 2737 2908 3079 3250 3421 3592 3763
Series1
301
302

FIG 3

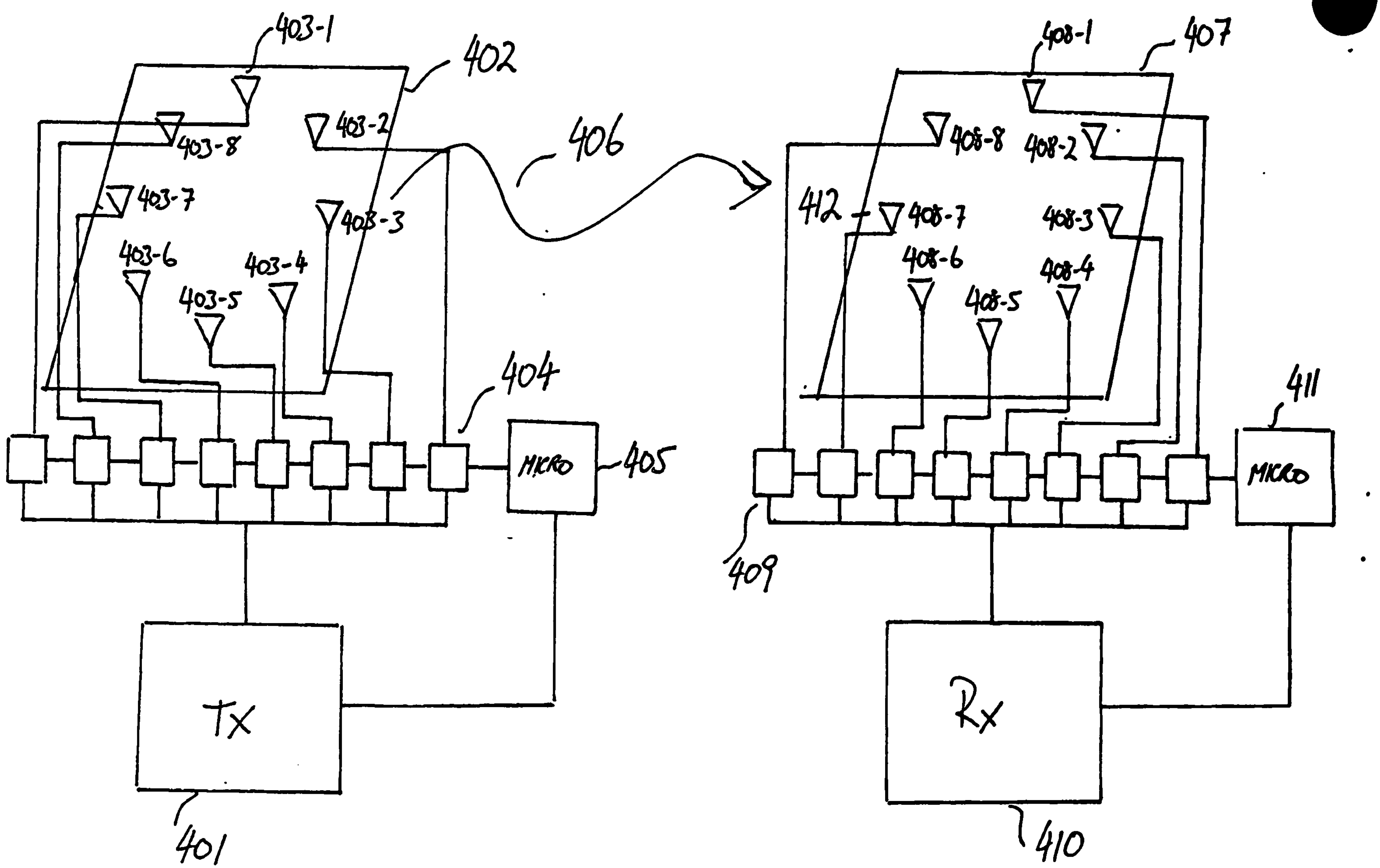
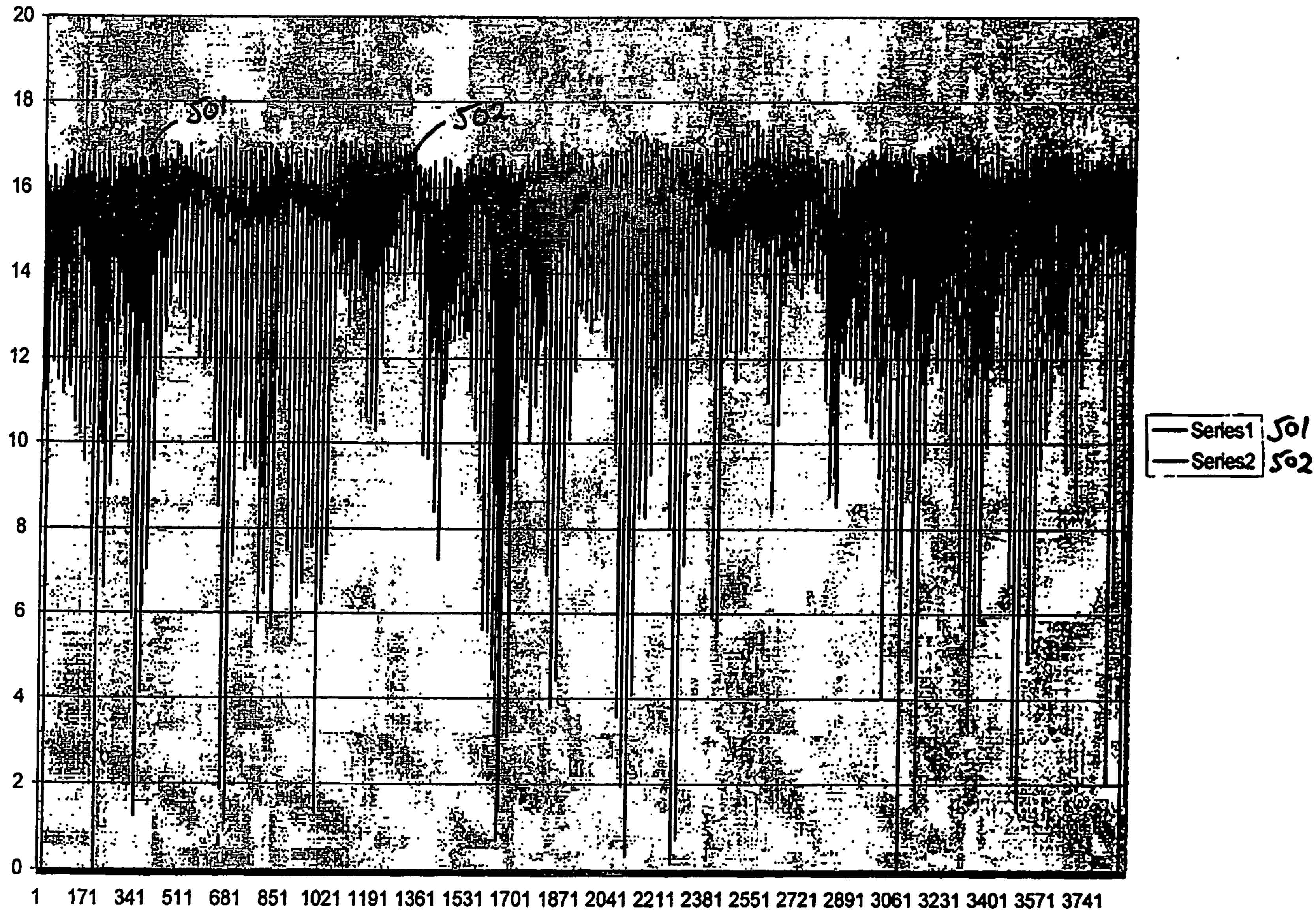

403-1
402
403-8
403-2
403-7
403-3
403-6
403-4
403-5
404
MICRO
405
Tx
401
406
408-1
407
408-8
408-2
412
408-7
408-3
408-6
408-4
408-5
411
MICRO
409
Rx
410

FIG 4



20
18
16
14
12
10
8
6
4
2
0
1
171
341
511
681
851
1021
1191
1361
1531
1701
1871
2041
2211
2381
2551
2721
2891
3061
3231
3401
3571
3741
501
502
Series1
Series2

FIG 5

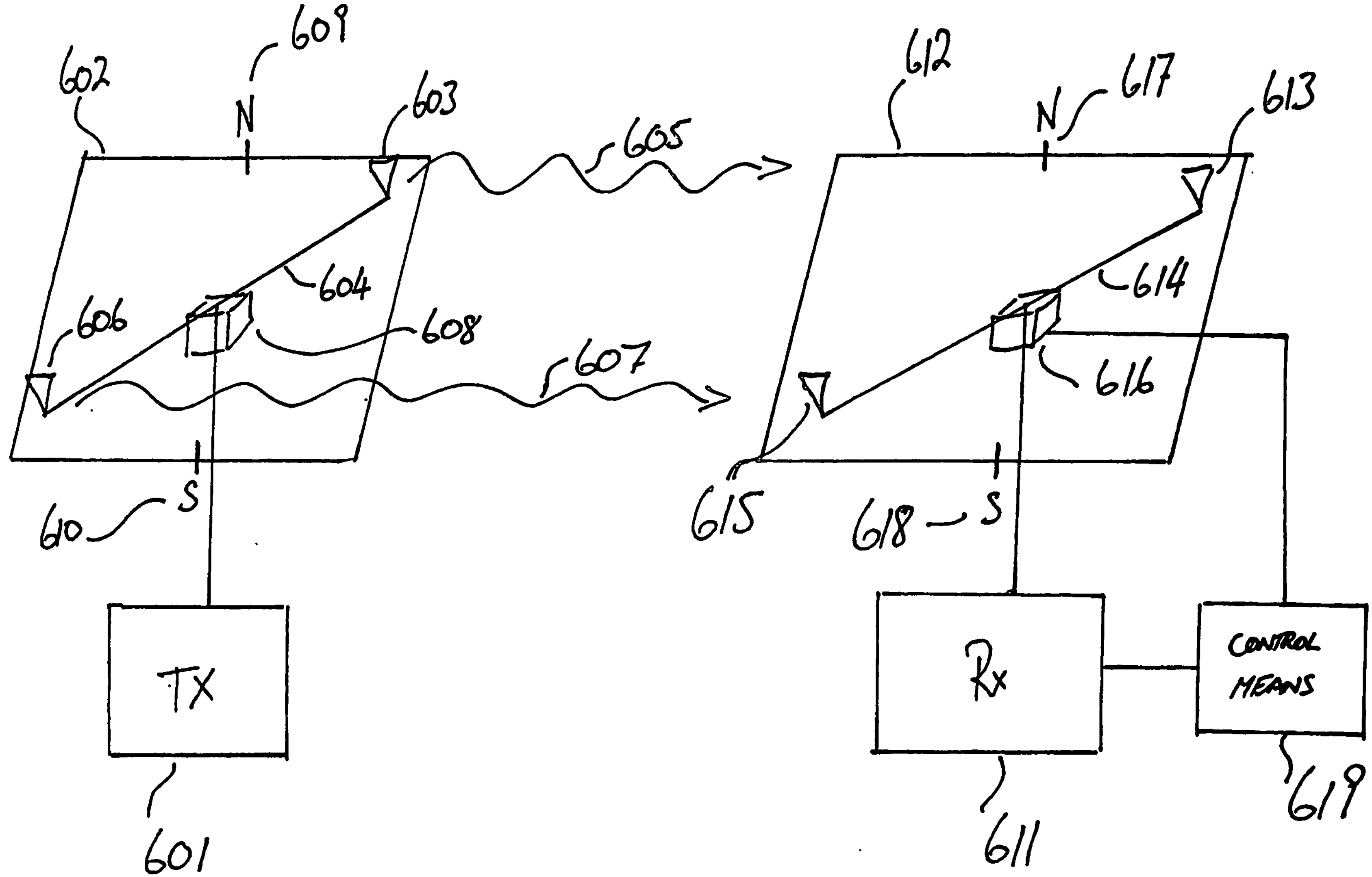

602
609
N
603
605
606
604
608
607
S
610
TX
601
612
617
N
613
614
616
615
618
S
Rx
CONTROL MEANS
611
619

FIG 6